Letter of Intent for RHIC Experiment

Two-Arm Electron/Photon/Hadron Spectrometer TALES Collaboration

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1 Introduction

With the advent of RHIC, the study of nuclear matter will enter a new realm of extreme conditions of temperature and density. An exciting possibility is that the colliding nuclei will interact sufficiently to come to equilibrium so that the energy of the incident beams will be dissipated by compression and heating in the large volume of nuclear matter. Under such conditions, it is expected that the system will undergo a phase transition from a state of nucleons containing bound quarks and gluons to a state of deconfined quarks and gluons, in chemical and thermal equilibrium, covering nearly the entire volume of the colliding nuclei, a volume much larger than the characteristic hadronic length scale. This new state of matter is called the Quark Gluon Plasma, or Quark Matter [1][2].

It is possible that the QGP will become self-evident when just a few ultra high energy central nuclear collisions are observed. A more likely outcome is that the existence of the QGP will have to be determined from a comprehensive and systematic set of experimental data exhibiting several striking signatures "which can be interpreted in a unified way as manifestations of QGP production"[3].

The signatures proposed for the QGP include both hadronic and leptonic modes. For instance, chemical and thermal equilibrium are tested by measuring the temperature ($< p_T >$) and relative abundance of identified charged hadrons[4][5]. The existence of a phase transition may be inferred[6][7] from the variation of the temperature with increasing particle or energy density, dn/dy or $dE_T/d\eta$, correlated with large fluctuations in these densities in a limited region of rapidity (~ 1 unit), on an event-by-event basis. Identical particle interferometry [8] may be used to estimate the size of the thermalized QGP. Lepton pairs are important in at least two ways: low-p_T, low-mass lepton pairs are a probe of the thermal equilibrium of the system and of the transition temperature[9]; while J/Ψ production (suppression)[10] is a probe of the deconfinement and Debye screening of color charge in the QGP. "Jet quenching" may be another example of a process that demonstrates deconfinement[11] and jet effects can probably be observed at RHIC by measurement of one or a few leading high p_T hadrons[12], or by direct single photon production[13].

In order to discover and prove the existence of the QGP, it would seem desirable to have a detector which is sensitive to as many of the proposed "signatures" as possible, so that they could all be observed and turned on and off in a predictable, reproducible, controllable and unified way. By emphasizing an open geometry experiment, optimized for detecting low-mass, low-p_T electron-positron pairs, we believe that a reasonably comprehensive measurement of the majority of the QGP signatures can be obtained.

2 Physics Motivation and Goals

2.1 Dielectron Production

The primary physics goal to be pursued with the proposed detector is the detection of quark-gluon plasma through the measurement of soft e^+e^- pairs, with a particular emphasis on the low-mass continuum below $M_{e^+e^-} <$ a few GeV/c^2.

The importance of *penetrating probe* cannot be over-emphasized: Even if a QGP is formed in the early stage of a nucleus-nucleus collision, the signals from the QGP phase may be buried under the backgrounds from the hadronic phase. We can only probe the hot dense matter by using penetrating probes such as photons or dileptons. After the transition to the QGP is detected by whatever signal, the details of the QGP phase can be better studied by clean penetrating probes, free from the final-state strong interactions.

Since the temperature, or the average energy per quanta, of the QGP phase is expected to be a few hundred MeV, low-p_T dilepton spectra below $\sim$ a few GeV/c^2 (and direct photons, which can be also studied with the proposed detector) should provide best signatures of the QGP formation[9,14].

On the other hand, lepton pairs in higher-mass region ($M_{\ell^+\ell^-} > 3$ Gev/c^2) should mainly come from initial hard scattering processes, hence they carry little information of the thermalized QGP state (of course, measurements of higher-mass pairs are interesting in their own right, *e.g.*, structure-function distortion due to nuclear effect, *etc.*).

There are several characteristics which can be used to distinguish thermal production of e^+e^- pairs by the QGP from other sources. The lepton pairs that are characteristic of the hadronic phase or hot pion gas exhibit peaks at the vector mesons (ρ^0, ω, ϕ). On the other hand, since such mesons cannot exist (at least at the same mass as in the hadronic phase) in the QGP, the lepton pairs are observed as an enhancement of continuum specrtra. For thermal production[9], the number of lepton pairs per unit of rapidity is proportional to the square of charged particle density dn/dy (or energy density $dE_T/d\eta$); and furthermore this ratio is proportional to the transition temperature T_c. Also, the transverse momentum, and invariant mass dependence of the cross section are not independent but depend only on the transverse mass m_T.

Recently, much theoretical work has been done to study the consequences of chiral symmetry restoration. It is conjectured that meson (ρ, ϕ, ω) masses would decrease at high temperatures. Should such changes occur, they can be best studied by measuring lepton pair spectra; the resonant shapes of these mesons may change, or there may even appear satellite peaks or shoulders in the invariant-mass spectra. The use of hadronic decay modes to detect the mass-shift effect should be quite difficult because of the large final-state hadronic interactions. At present, it is not possible to reliably predict what the spectrum should look like. The prediction depends sensitively on the QCD chiral restoration scenario, as well as on the collision dynamics. We believe that only the detectors capable of measuring lepton-pair continuum (good mass resolution, good background rejection) can successfully attack this intriguing problem.

High resolution measurement of low-mass virtual-photon continuum can only be achieved by detecting electron-positron pairs; clearly, muon-pair detection is not a suitable method to attack the important physics issues as described above. However, e^+e^- detection is a nontrivial task due to the overwhelmingly large combinatorial background from π^0 and η Dalitz decays. The key to the successful measurement of the low-mass continuum is i) positive identification of electrons and positrons in large hadronic (and photon) background, ii) precise measurement of their momenta, and iii) rejection of Dalitz-decay pairs.

The study of the opening-angle distribution of Dalitz-decay pairs shows that it is essential to reject pairs with relatively small ($\theta < 15^\circ$) opening angles, and that the identification is done in a field-free region, so that the asymmetric pairs which produce the most serious background do not open up, or worse, spiral so badly that the lower energy member of the pair is lost.

The proposed detector system can attain these goals by the combination of ring-imaging Čerenkov counters, time projection chambers and highly-segmented electro-magnetic calorimeters. The details will be provided in the next section.

2.2 π^0, η and direct photon measurements

Direct photon production is another penetrating probe of the QGP, complementary to e^+e^- production, and should exhibit the same characteristic thermal signatures[9][14]. Thermal production of direct photons is expected to dominate in the range $2 \leq p_T \leq 4$ GeV/c, while hard scattering production of direct photons via the $g + q \rightarrow \gamma + q$ subprocess, should dominate for $p_T \geq 5$ GeV/c.

The main problem with detecting direct photon production is the inevitable background of photons from the decays of the leading hadrons: $\pi^0 \rightarrow \gamma + \gamma$, $\eta^0 \rightarrow \gamma + \gamma$ and perhaps even $\omega^0 \rightarrow \pi^0 + \gamma$. Thus the detector must have the capability to measure in detail the production of π^0, η^0 and other mesons which decay to photons in order reconstruct the background to direct photon production. Since the internal (or *Dalitz*) conversion of these hadronic photon sources is also the principal background to the e^+e^- pair measurement, it is natural (and traditional[15]) for detectors of e^+e^- production in hadron collisions to also provide excellent measurements of neutral hadron, charged hadron and direct photon production[13]. In fact, this is how jets and hard scattering phenomena were originally discovered at the CERN ISR[16]. At RHIC, it appears that the production of one or a few leading high p_T hadrons[12] may be the best probe of jets and minijets. This will involve measurements of semi-inclusive single and few particle spectra with at least two different values of $\sqrt{s_{NN}}$ and two different ions (e.g. Au+Au, Cu+Cu).

2.3 Global event characterization

Measurements of E_T and $dE_T/d\eta$ distributions have proved to be an important analytical tool for the soft multiparticle interactions which are predominant in Relativistic Heavy Ion Collisions[18]. Experiments at BNL and CERN have shown that E_T distributions from nuclear collisions are largely dominated by the nuclear geometry. A coarse-segmentation electromagnetic barrel calorimeter covering $0 < |\eta| < 2$, and a coarse-segmentation electromagnetic endcap calorimeter covering $2 < |\eta| < 6$ will be used as our global event characterization device (E_TCAL). The E_TCAL will supply an estimator of $dE_T/d\eta$ over nearly the full phase space $|\eta| < 6$ and thus provide an excellent "centrality" measurement on an event by event basis. It will be used as one of the primary triggers of the experiment.

From measurements in high energy particle physics, it is expected that the average rapidity distribution of the charged particle production, dn/dy, or equivalently of transverse energy emission $dE_T/d\eta$, will exhibit a very broad and flat plateau, possibly stretching out to ± 6 units of rapidity. It is also possible that event-by-event fluctuations of $dE_T/d\eta$ are signatures of interesting physics such as correlations, "intermittency", or a phase transition. Van Hove[7] has suggested that the rapid expansion of the QGP would cause an explosive process or "deflagration" into a few droplets in which the "*latent heat of the plasma transforms into collective flow energy*" which would be manifested by large event-by-event fluctuations in $dE_T/d\eta$ over a range $\sim$1 unit of rapidity. These fluctuations will be detected in the E_TCAL, and when they occur at $\eta \simeq 0$, they can be analyzed by the central detector for other evidence of the characteristic QGP signatures. EM calorimeters are used in both the central two arm spectrometer and the E_TCAL to ensure that the particles observed in the two arm spectrometer are representative of the global trigger when the fluctuation is selected at $\eta \simeq 0$.

2.4 Identified Hadron p_T Spectra

Measurement of semi-inclusive hadron spectra with good particle-ID, in combination with the global event characterization, would give us information on the breakup stage of the collisions. The interesting kinematical region will be below $\sim$ 2 GeV/c, where we expect hadrons from the hot hadronic gas. By comparing the spectra among various hadrons, we might be able to deduce the evidence of the hydrodynamical flow. Change of relative yields and spectral shape among various hadrons correlated to the fluctuations in $dE_T/d\eta$ could be a clear demonstration of the explosive QGP expansion processes.

For such measurements, we think it is sufficient to have about 100 elements of time-of-flight counters just in front of the EM calorimeter. With flight path of $\sim$ 3.5 meters and with $\sim$ 70 psec timing resolution, we will be able to identify $\pi^{\pm}$ and $K^{\pm}$ up to 2 GeV/c, and $p^{\pm}$ up to 3 GeV/c.

It is predicted that at RHIC energy a baryon-free central region will be formed at mid-rapidity. This prediction is based on an extrapolation from the baryon stopping power measured at much lower energies ($\sqrt{s}$ = 20 GeV), and should be experimentally verified at RHIC. The stopping power of baryons can be best studied by measuring the dn/dy distribution of identified hadrons in forward-rapidity regions; it is also useful to study the effect of baryon density on the particle production.

We can take advantage of the open geometry of the proposed system, and combine the present system with an optional forward small-acceptance spectrometer to extend the dn/dy measurement to wider rapidity range, and to correlate the hadron spectra with the global event characterization.

2.5 Charm Production

Direct identification of charm particles in the RHIC environment will be very difficult. Leptons from semileptonic decays of charm particles (mainly D,D^*) may possibly constitute the major background in the dielectron mass spectrum from 1 to 3 GeV.

The charm signal in hadron collisions (without a vertex detector) has been seen in the single electron channel (Dalitz conversions rejected) at a level $e/\pi \sim 10^{-4}$ for $p_T \sim 1.3$ to 1.5 GeV/c. At the ISR the e/π ratio varied systematically by a factor of $\sim$ 1.8 from 30 to 60 GeV, and by a fit to this data would be predicted to be 2.6×10^{-4} at $\sqrt{s} = 600$ GeV[15]. Recent measurements at CERN give roughly this value[17]. Thus, it is likely that e/π at RHIC is large and is a good measure of CHARM production. In particular, production of multiple high p_T (> 1.5 Gev/c) electrons on the same side may be important—and could serve as a CHARM signal, as well as an estimator of the combinatoric background due to CHARM in the opposide-side e^+e^- spectrum.

3 Overview of the proposed central detector

The proposed central detector system is schematically depicted in Fig.1. This detector has been designed so as to fulfill the physics goals described in detail in the previous section, with an emphasis on the measurement of soft low-mass e^+e^- pairs.

It is an open-geometry double-arm spectrometer, consisting of two identical arms on both sides of the beam pipe (each covering $-0.2 < \eta < 0.2$, $-30^o < \phi < 30^o$), with a gas ring-imaging Čerenkov (RICH) counter on each arm. The RICH counters are placed close to the beam pipe, in a field-free region, and are used to identify electrons and to reject small-angle e^+e^- pairs. A heavy-metal shield is placed between the beam pipe and the RICH photon detectors so as to protect the photon detectors against the high flux of charged particles.

Charged particle tracking starts at 1.5 m from the collision diamond. Each arm has a time projection chamber (TPC) placed in an H-type dipole magnet, and a high-resolution drift chamber system. The expected number of charged particles entering each arm is about 80 (for central Au+Au collisions).

A RICH detector has a high angular resolution, and is used to determine the direction cosines of the electron (positron) tracks. This angular information is used to connect the electron track in the RICH to the charged tracks detected in the TPC-DC tracker.

Behind the tracking volumes, we propose to install highly-segmented high-resolution electromagnetic calorimeters. The calorimeters provide additional electron identification power, and can be also used to study γ, π^0 and η spectra.

A coarse-segmentation electromagnetic barrel calorimeter covering $0 < |\eta| < 2$, and a coarse-segmentation electromagnetic endcap calorimeter covering $2 < |\eta| < 6$ will be used as our global event characterization (impact-parameter trigger) device (E_TCAL).

The RICH optics design and the field uniformity on the TPC are the two major parameters which has lead us to the present detector geometry (η acceptance in particular), and the proposed geometry is the best optimization we have achieved so far. The overall geometry optimization is an important R&D item.

Another major issue is the ability to trigger on electrons of a minimum p_T and e^+e^- pairs of a minimum invariant mass in real time. This would involve a first level trigger on a cluster in the EM calorimeter followed by a second or higher level trigger in which the cluster would be correlated with an electron track identified with the RICH.

4 Description of detector components and expected performance

4.1 Tracking

Tracking starts at 1.5 m from the collision diamond. Each spectrometer arm has a dipole magnet with a maximum strength of 1 T-m, and a TPC inside the magnet. High-resolution drift chambers (projective readout) will be placed at the entrance of the magnet, and at 1m behind the magnet. The TPC is our primary pattern recognition device; the drift chambers, which have better spatial resolution and better two-track separation as compared to the TPC, are used to achieve good momentum resolution ($\delta p/p < 0.5\%$ at 1 GeV/c).

Issues of Magnetic field strength, momentum resolution, acceptance and triggering

The strength and uniformity of the magnetic field are important concerns. The TPC requires a purely axial magnetic field (B_z) over its volume. The specification on the other components is to be determined but is expected to be similar to that of the ALEPH detector, averaged over the gap height of one meter. The width of the magnet aperture is approximately 3 meters, and the length through the magnet is assumed to be 1.5 meters, including shielding plates. The good field region in which the TPC is located is assumed to occupy the central 1.0 meter. A 120D36 with shielding plates is the approximate scale of the required magnet and would be the starting point for optimization and field shape calculations.

The issues of lepton-pair acceptance and momentum resolution pose conflicting requirements on the strength of the magnetic field. For the purpose of ease of triggering and maximum acceptance, minimum bending of the charged particles is preferred—a field strength of 0.3 T, and effective length 1.0 m, for an integral *Bdl* of 0.3Tm (0.090 GeV/c). For the purpose of best momentum resolution, the field can be increased to 1.0 T for a bending strength of 1 Tm or 0.300 GeV/c.

The TPC, with its 3-dimensional pattern recognition, serves to define the tracking. Eleven equally spaced stations with σ =1 mm resolution cover the 1 meter tracking length of the TPC in N=10 intervals of 10 cm each. Two or three drift chambers with better spatial (σ =0.2 mm) and two track resolution are placed externally to the magnet to improve the momentum measurement.

In the initial configuration of the experiment—the bending is vertical, in the azimuthal direction—so that the small size of the beam (σ =0.5 mm) is used to constrain the tracking resolution without need for a microvertex detector. [1]

For most charged particles entering the spectrometer, multiple scattering is the dominant factor which determines the momentum resolution. This is estimated to be equivalent to 1 % of a radiation length of material: $\sigma_p/p = 1.7\%$ (0.5%) for the low (high) field settings.

Vertex determination

The precise determination of vertex position is important to achieve good momentum resolution, and to associate the electron track seen in the RICH with a charged particle track measured by the TPC-DC tracker. In the bending plane (r), the small size of the beam is used to constrain the tracking. In the non-bending direction (z-direction, i.e., along the beam), it should be possible to determine reaction vertex on an event by event bases from reconstructed charged-particle tracks. Time-of-flight difference between forward and backward counters should also provide precise information on the z-vertex position.

4.2 Electron-pair reconstruction and Dalitz-decay rejection

Electrons are identified by a gas RICH counter which fills the volume between the diamond and the magnet. Electron track candidates found by the RICH counters are matched to the tracks reconstructed in the TPC, and are further verified by the electromagnetic calorimeter placed at R = 3.6 m. An overall e/π separation of 10^{-5} to 10^{-4} should be achievable with this scheme.

[1] For subsequent runs where high rate is at a premium, it might be desirable to add low β quadrupoles and also to rotate the magnets so as to bend in the polar plane. This would increase the η acceptance and decrease the azimuthal acceptance, but would result in a net increase of a factor of $\sim$ 2 in the e^+e^- pair acceptance. A microvertex detector would be required.

It will be shown in the following that Dalitz decay background events from π^0 and η decays can be effectively rejected if we throw away an electron track associated with an adjacent positron track.

4.2.1 RICH Counter

The RICH counter consists of a mirror system and a photon readout system. They will be installed in a container, filled with suitable radiator gas at 1 atm. The gas should have a relatively large refractive index to obtain enough number of photons, but it should have a long radiation length to minimize γ conversion. A possible choice is an ethane-isobutane mixture. The RICH counter is installed in front of the magnet placed at R=1.5m. The radiator length is $\sim$ 1 m. The expected (and also required) number of detected photons per track is 10 $\sim$ 15.

The current design parameters are summarized below in Table I. A hybrid mirror system, consisted of two spherical mirrors with radius of 1700 mm, is placed at 1.3m from the diamond. The two mirrors are tilted $\pm$16 degrees, respectively, so that the image of the Čerenkov rings are focused onto the photon-counters placed outside the spectrometer acceptance.

Table I. Summary of the RICH Counter Design Parameters

number of mirrors:	2 modules / arm (plane symmetry at z=0)
mirror curvature:	1700mm
mirror position:	1300mm from the beam axis.
coverage angle:	$\Delta\theta$ = 20 degrees / module, and
	$\Delta\phi$ = 65 degrees.
tilt angle:	16 degrees.
number of detectors:	2 modules / arm (plane symmetry at z=0)
detector size:	400mm $\times$ 500mm / module
detector position:	550mm from the beam axis

A simple simulation was performed to see the dependence of the pixel size of the photon counter on the resolution of ring center determination. For a typical ring size of 5 cm at the counter, resolution of less than 2 mm (rms) was achieved for 10 detected photons with the pixel size of 1 cm $\times$ 1 cm. With a mirror curvature of 1700 mm, the angular resolution is less than 7.0 mili-radian (3 rms), and the resultant solid-angle resolution is 50 micro-steradian. We expect $dN_c/d\Omega \sim 200$/sr at the central rapidity in central Au + Au collisions. The solid-angle occupied by each track is $\sim$ 5 msr. The above result indicates that the loss of tracks due to track association between the RICH counter and the particle tracking system can be kept as low as a few %, assuming a better or comparable resolution in the particle tracking system.

Optics

The optics of the Čerenkov photons is one of the main issues in the design work. Fig. 2 shows a result of the simulation study of Čerenkov optics with the currently adopted design parameters. In this (two-dimensional) calculation, the three tracks with directional angles 70, 80 and 90 degrees from the beam axis, are generated from the three different collision points -10, 0 and + 10 cm, relative to the center of the collision points. One can see that the Čerenkov images from the tracks with a same direction, are well focused on a same position in a focal plane, independent of where the tracks originate.

Readout

Readout of the Čerenkov ring-image is our-high priority R&D project for RHIC. Although readout by UV-photon sensitive chambers is currently widely adopted, we are trying to pursue alternative ways; readout by (1) array of photomultiplier tubes (PMT), (2) multi-anode PMT's, or (3) SSD array. The method (1) will be costly but is straight-forward, and we can take this as our fall-back position. The method (2) is very promising, since UV-sensitive multi-anode tubes with fine-mesh dynodes (100 mm square, 2.5mm anode spacing) should shortly become available. The method (3) is to use an array of photo-avalanche diodes. Some diodes with one-photon sensitivity are available but they have tiny active area, and have to be cooled. Nevertheless, the method is very attractive, since it will provide us with great flexibility in designing the system. We notice that R&D's to achieve one photon sensitivity at room temperature are in progress.

4.2.2 Electron-pair reconstruction and Dalitz-decay rejection - expected performance

An extensive Monte Carlo study on the electron-pair reconstruction efficiency and Dalitz-decay rejection efficiency was done. We assumed a Au+Au central collision, and included both π^0 and η Dalitz decays (the η/π^0 yield ratio was assumed to be 20%). Decays of ρ, ω and ϕ were also included in the simulated events.

The distribution of the opening angles of the Dalitz-decay e^+e^- pairs is peaked at small angles. We found that if we discard an electron/positron if there is a Čerenkov hit within a cone angle of 15°, we can improve the signal-to-noise ratio of the e^+e^- pair measurement by a factor 35 (at 1 GeV/c^2) with only 30% loss in the true-pair reconstruction efficiency.

In Fig.3, we show the e^+e^- pair invariant mass spectrum without Dalitz decay rejection (dashed histogram), and with rejection (solid histogram), plotted in 10 MeV bins. The statistics corresponds to about 2×10^7 Au+Au central collisions. The discrete peaks of ω and ϕ decays are clearly visible.

Overlaid, we show in Fig.3 two curves; the solid curve is the estimated pair continuum from the QGP (Kajantie et al.[9]), and the dashed curve is the magnitude of the *anomalous* continuum enhancement observed so far in various measurements[19].

The $M_{e^+e^-}$ acceptance of the detector system is shown in Fig.4 (we assumed that $d\sigma/dydM_T \propto M_T \exp(-M_T/T)$ with $T = 160$ MeV).

4.3 EM Calorimeter

A highly-segmented electromagnetic calorimeter will be placed at $R = 3.6$ m; the area covered is about 8 m^2/arm, each segmented into about 5000 blocks of crystals such as

PbF_2. In Fig.5, we show a result of a Monte Carlo simulation which demonstrates the π^0 reconstruction capability of the EM calorimeter. The choice of the calorimeter crystal is an important R&D subject.

The highly segmented EM calorimeter is the ideal device to measure π^0 and η^0 production via the 2-γ decay and to search for direct photon production. The two most severe detector limitations on π^0 and direct-γ production concern: (i) the minimum separation at which two photons can be resolved; and (ii) the minimum energy photon that can be paired to form a π^0 or η^0 above noise and combinatorics. For this discussion, the minimum energy photon is taken to be 1.0 GeV. Also, it is assumed that photons will be resolved if they are separated by 3 block widths in the EM calorimeter, or 120 mm. In this case, π^0 can be reconstructed between 2 and 8 GeV/c in p_T, and η^0 up to 24 GeV/c. If the two-γ resolution can be improved to 50 mm, then π^0 can be measured up to 20 GeV/c in p_T. It is also possible to measure π^0 and direct-γ production statistically, by the *conversion probability* method[20], using a converter just in front of the EM calorimeter. This has different systematics to combinatorics than the reconstruction method. It also involves an additional scintillator in front of each EM calorimeter cell. Considerable further study is warranted on many of these issues.

4.4 Global event characterization

A coarse-segmentation electromagnetic barrel calorimeter covering $0 < |\eta| < 2$, and a coarse-segmentation electromagnetic endcap calorimeter covering $2 < |\eta| < 6$ will be used as our global event characterization device (E_TCAL). Conventional lead-scintillator or spaghetti type construction appear to be suitable. The purpose of this device is to characterize the collision by providing an estimator of $dE_T/d\eta$ over nearly the full phase space $|\eta| < 6$. Also, it will be used as one of the primary triggers of the experiment.

Strong Impact of RHIC machine on the design of E_TCAL

The design of the very forward E_TCAL is very strongly influenced by the parameters of the RHIC machine, in particular the 9 meter limitation due to BC1, (the $\sim$ 60 cm diameter of the BC1 cryostat), the minimum beam pipe diameter of 4 to 8 cm and the thickness of the beam pipe. The detector is assumed to be a lead-scintillator shower counter, roughly 20 radiation lengths thick, conventional or of the spaghetti type used in NA38. A shower containment of the order of a few centimeters in diameter is assumed, making 5 by 5 cm a reasonable segmentation. With this spatial resolution and segmentation, a minimum distance of 5 cm from the beam line seems appropriate, and consistent with the RHIC parameters.

A nice solution is found for an endcap calorimeter composed of 2 walls, one placed at 8.0 meters from the target, and the other at 2.0 meters. Two such endcap calorimeters are placed symmetrically on either side of the interaction region. The segmentation in polar angle is determined by the 5 cm limit. In azimuth, the full aperture is divided into 16 segments. At 8.0 meters, the detector starts at an inner radius of 50 mm from the beam axis and has five rings, spaced at 50 mm intervals, with the outer radius being 300mm. The coverage in η is $3.98 \leq \eta \leq 5.77$ in five intervals. The 2.0 meter wall starts at a radius of 75 mm, with nine

50 mm rings, and an outer radius of 525 mm. The η coverage is $2.05 \leq \eta \leq 3.98$ in nine intervals. The total number of elements in the endcap calorimeter is $14 \times 16 \times 2 = 448$. The E_TCAL will be constructed so that segments can be removed to allow for an aperture for a forward spectrometer.

These walls are relatively compact detectors. The forward (8 m) E_TCAL walls will also serve two additional purposes: (i) as beam-beam counters to indicate an interaction; (ii) for TOF measurement, to measure the interaction vertex. A time resolution of 100 psec would imply a measurement of the vertex to 1.5 cm. Scintillation or cerenkov leaves could be placed in front of the E_TCAL to improve the TOF resolution. At the smallest angle, $\theta = 0.36°$, the effective thickness of a simple cylindrical beam pipe is increased by a factor $\csc\theta$=160, so that a radial thickness of ~0.5 % of a radiation length is required so as to present less than 1 radiation length of material in front of the E_TCAL. This is roughly the same constraint on beam pipe thickness as given by the central electron spectrometer, so should be achievable. Alternatively, more complicated shaped beam pipes may be envisaged.

4.5 Optional forward spectrometer

Since there is an open space in the forward ($1 < |\eta| < 4$) region, addition of a forward spectrometer to measure charged particle single spectra is being considered.

4.6 Performance summary

The following table shows a summary of the expected performance of the proposed detector:

Pseudo rapidity range	$-0.2 < \eta < 0.2$
ϕ coverage	$-30° < \phi < 30°$, two arms
Single-particle momentum resolution	$\delta p/p = 0.5\%$ at 1 GeV/c
Single-particle acceptance	17 % / η
Charged particle multiplicity / arm	~ 80 (Au+Au central)
e^+e^- pair acceptance$^+$	1.3 % at J/Ψ, 0.6 % at $\phi(1020)$
e^+e^- pair mass resolution	7 MeV at 1 GeV/c^2
Dalitz-pair suppression	1/35 at $M_{e^+e^-} = 1.0$ GeV/c^2
e^+e^- pair S/N at 1 GeV	0.01 (Anomalous pair, without Dalitz rejection)
	0.5 (Anomalous pair, with Dalitz rejection)
	0.3 (QGP a la Kajantie, without Dalitz rejection)
	15 (QGP a la Kajantie, with Dalitz rejection)
J/Ψ yield	~ 40/ day (Au+Au, $L = 5 \times 10^{26}$)
ϕ yield	~ 90 / day (Au+Au, $L = 5 \times 10^{26}$)

+) Event rate = $L \times B\frac{d\sigma}{dy} \times Acceptance$